Study Material

Physics

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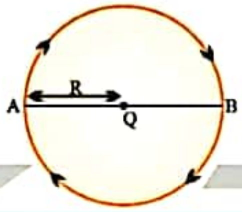


Chapter - 5

Motion

CHAPTER AT A GLANCE

Physical-State

- Rest
- Motion

Motion

- Uniform motion
- Non-uniform motion

Non-uniform Motion

- Accelerated motion
  - Uniformly accelerated motion
  - Non-uniformly accelerated motion
- Decelerated motion
  - Uniformly decelerated motion
  - Non-uniformly decelerated motion

Equations of Motion

- $v = u + at$ → First equation
- $s = ut + \frac{1}{2}at^2$ → Second equation
- $v^2 = u^2 + 2as$ → Third equation

Circular Motion

↓

An-accelerated motion

Contents :

(i) *Defination of rest and motion*

(ii) *Types of motion*

(iii) *Types of physical quantities*

(iv) *Distance, displacement and their differences*

(v) *Uniform and non-uniform motion and their types*

(vi) *Speed and velocity*

(vii) *Acceleration, decelerated motion*

(viii) *Graphical plotting of uniform and non-uniform motion*

(ix) *Equation of motion and their derivation*

Rest : A body is said to be in a state of rest when its position does not change with respect to a reference point.

Motion : A body is said to be in a state of motion when its position change continuously with reference to a point.

Motion can be of different types depending upon the type of path by which the object is going through.

(i) Circulatory motion/Circular motion – In a circular path.

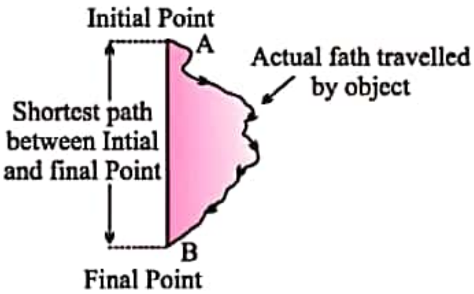
(ii) Linear motion – In a straight line path.

(iii) Oscillatory/Vibratory motion – To and fro path with respect to origin.

Scalar quantity : It is the physical quantity having own magnitude but no direction *e.g.*, distance, speed.

Vector quantity : It is the physical quantity that requires both magnitude and direction *e.g.*, displacement, velocity.

Distance and Displacement :



- The actual path or length travelled by a object during its journey from its initial position to its final position is called the distance.
- Distance is a scalar quantity which requires only magnitude but no

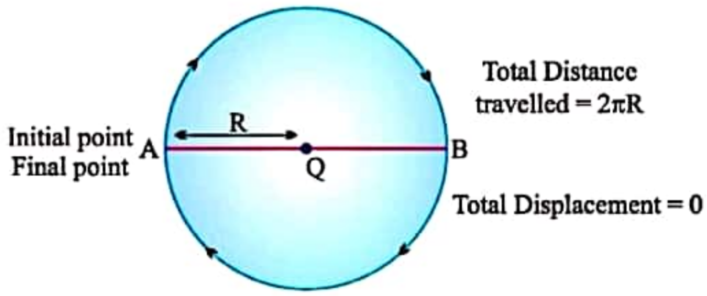
direction to explain it.

Example, Ramesh travelled 65 km. (Distance is measured by odometer in vehicles.)

- Displacement is a vector quantity requiring both magnitude and direction for its explanation.

  Example, Ramesh travelled 65 km south-west from Clock Tower.

- Displacement can be zero (when initial point and final point of motion are same) *Example,* circular motion.



Difference between Distance and Displacement

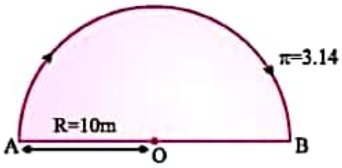
Distance	Displacement
1. Length of actual path travelled by an object.	1. Shortest length between initial point and far point of an object.
2. It is scalar quantity.	2. It is vector quantity.
3. It remains positive, can't be '0' or negative.	3. It can be positive (+ve), negative (-ve) or zero.
4. Distance can be equal to displacement (in linear path).	4. Displacement can be equal to distance or its lesser than distance.

Example 1. *A body travels in a semicircular path of radius 10 m starting its motion from point 'A' to point 'B'. Calculate the distance and displacement.*

Solution : Total distance travelled by body, S = ?

Given, $\pi = 3.14$, $R = 10$ m

$S = \pi R$



$$= 3.14 \times 10 \text{ m}$$

$$= 31.4 \text{ m}$$ **Ans.**

Total displacement of body, D = ?

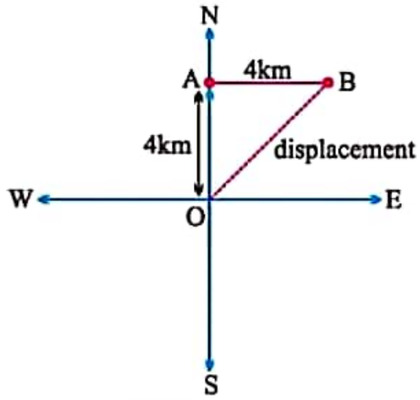
Given, $R = 10 \text{ m}$

$$D = 2 \times R$$

$$= 2 \times 10 \text{ m} = 20 \text{ m}$$ **Ans.**

Example 2. *A body travels 4 km towards North then he turn to his right and travels another 4 km before coming to rest. Calculate (i) total distance travelled, (ii) total displacement.*

Solution :



Total distance travelled $= OA + AB$

$$= 4 \text{ km} + 4 \text{ km}$$

$$= 8 \text{ km}$$ **Ans.**

Total displacement $= OB$

$$OB = \sqrt{OA^2 + OB^2}$$

$$= \sqrt{(4)^2 + (4)^2}$$

$$= \sqrt{16 + 16}$$

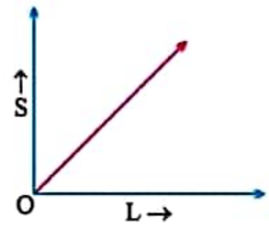
$$= \sqrt{32}$$

$$= 5.65 \text{ km}$$ **Ans.**

Uniform and Non-uniform Motions

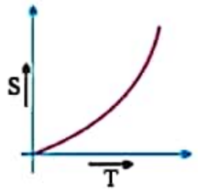
- ***Uniform Motion :***

  When a body travels equal distance in equal interval of time, then the motion is said to be uniform motion.

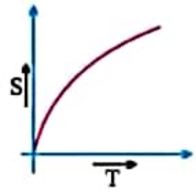


- **Non-uniform Motion :**

  In this type of motion, the body will travel unequal distances in equal intervals of time.



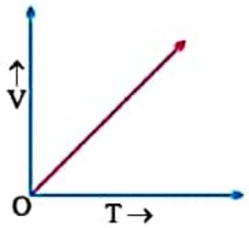
Continuous increase in slope of curve indicates accelerated non-uniform motion.



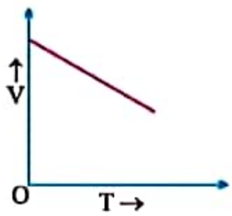
Continuous decrease in slope of curve indicates decelerate non-uniform motion.

Non-uniform motion is of two types :

(i) ***Accelerated Motion :*** When motion of a body increases with time.



(ii) ***De-accelerated Motion :*** When motion of a body decreases with time.



Speed : The measurement of distance travelled by a body per unit time is called speed.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$v = \frac{s}{t}$$

- SI unit = m/s (meter/second)
- If a body is executing uniform motion, then there will be a constant speed or uniform motion.
- If a body is travelling with non-uniform motion, then the speed will not remain uniform but have different values throughout the motion of such body.
- For non-uniform motion, average speed will describe one single value of speed throughout the motion of the body.

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Example : *What will be the speed of body in m/s and km/hr if it travels 40 kms in 5 hrs ?*

Solution :

Distance (s) = 40 km

Time (t) = 5 hrs.

$$\text{Speed (in km / hr)} = \frac{\text{Total distance}}{\text{Total time}}$$

$$= \frac{40 \text{ km}}{5 \text{ hrs}}$$

= 8 km/hr **Ans.**

Speed (in m/s) = ?

40 km = 40 × 1000 m = 40,000 m

5 hrs = 5 × 60 × 60 sec.

$$= \frac{40 \times 1000 \text{ m}}{5 \times 60 \times 60 \text{ s}}$$

$$= \frac{80 \text{ m}}{36 \text{ s}}$$

= 2.22 m/s **Ans.**

Conversion Factor

Change from km/hr to m/s $= \dfrac{1000\,\text{m}}{60 \times 60\,\text{s}}$

$$= \frac{5}{18}\,\text{m/s}$$

Velocity : It is the speed of a body in given direction.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

- Velocity is a vector quantity. Its value changes when either its magnitude or direction changes.
- For non-uniform motion in a given line, average velocity will be calculated in the same way as done in average speed.

$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time}}$$

- For uniformly changing velocity, the average velocity can be calculated as follows :

$$\text{Avg velocity} = \frac{\text{Initial velocity} + \text{Final velocity}}{2}$$

$$V_{(avg)} = \frac{u+v}{2}$$

where, u = initial velocity, v = final velocity

SI unit of velocity = ms^{-1}

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

$\because$

- It can be positive (+ve), negative (-ve) or zero.

Example 1 : *During first half of a journey by a body it travel with a speed of 40 km/hr and in the next half it travels with a speed of 20 km/hr. Calculate the average speed of the whole journey.*

Solution : Speed during first half (v_1) = 40 km/hr

$$\text{Speed during second half } (v_2) = 20 \text{ km/hr}$$

$$\text{Average speed} = \frac{v_1 + v_2}{2}$$

$$= \frac{40+20}{2} = \frac{60}{2}$$

$$= 30 \text{ km/hr}$$

Average speed by an object (body) = 30 km/hr. **Ans.**

Example 2 : *A car travels 20 km in first hour, 40 km in second hour and 30 km in third hour. Calculate the average speed of the train.*

Solution : Speed in Ist hour = 20 km/hr, *Distance travelled during 1st hr* $= 1 \times 20 = 20$ *km*

Speed in IInd hour = 40 km/hr, *Distance travelled during 2nd hr* $= 1 \times 40 = 40$ *km*

Speed in IIIrd hour = 30 km/hr, *Distance travelled during 3rd hr* $= 1 \times 30 = 30$ *km*

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{20+40+30}{3} = \frac{90}{3} = \frac{20+40+30}{1+1+1}$$

$$= 30 \text{ km/hr}$$ **Ans.**

Acceleration : Acceleration is seen in non-uniform motion and it can be defined as the rate of change of velocity with time.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time}}$$

$$a = \frac{v-u}{t}$$

where, v = final velocity, u = initial velocity

If $v > u$, then 'a' will be positive (+ve).

Retardation/Deaceleration : Deaceleration is seen in non-uniform motion during decrease in velocity with time. It has same definition as acceleration.

$$\text{Deaceleration} = \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$a' = \frac{v-u}{t}$$

Here $v < u$, 'a' = negative (-ve).

Example 1 : *A car speed increases from 40 km/hr to 60 km/hr in 5 sec. Calculate the acceleration of car.*

Solution : $u = \frac{40\text{ km}}{\text{hr}} = \frac{40 \times 5}{18} = \frac{100}{9} = 11.11\text{ ms}^{-1}$

$v = \frac{60\text{ km}}{\text{hr}} = \frac{60 \times 5}{18} = \frac{150}{9} = 16.66\text{ ms}^{-1}$

$a = ?$ $\qquad t = 5$ sec.

$$a = \frac{v-u}{t}$$

$$= \frac{16.66 - 11.11}{5}$$

$$= \frac{5.55}{5}$$

$$= 1.11\text{ ms}^{-2}$$ **Ans.**

Example 2. *A car travelling with a speed of 20 km/hr comes into rest in 0.5 hrs. What will be the value of its retardation ?*

Solution : $v = 0$ km/hr

$u = 20$ km/hr

$t = 0.5$ hrs

Retardation, $a' = ?$

$$a' = \frac{v-u}{t}$$

$$= \frac{0-20}{0.5}$$

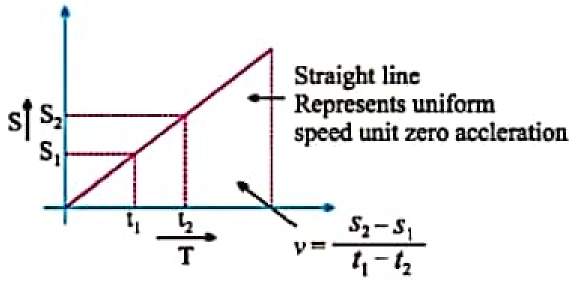
$$= -\frac{200}{5}$$

$$= -40\text{ km/hr}^2$$ **Ans.**

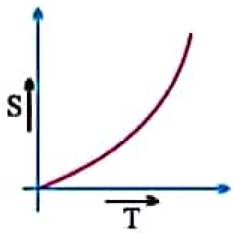
Graphical Representation of Equation

(i) Distance-Time Graph : s/t graph :

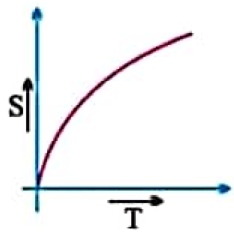
(a) s/t graph for uniform motion :



(b) s/t graph for non-uniform motion :

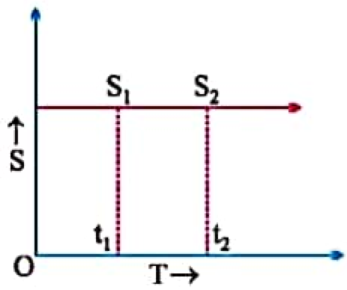


Continuous increase in slope of curve indicates accelerated non-uniform motion.



Continuous decrease in slope of curve indicates decelerate non-uniform motion.

(c) s/t graph for a body at rest :



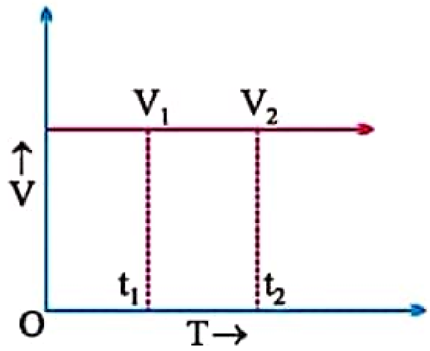
$$v = \frac{s_2 - s_1}{t_2 - t_1}$$

But, $s_2 = s_1$

$$\therefore \quad v = \frac{0}{t_2 - t_1} \quad \text{Or} \quad v = 0$$

(ii) Velocity-Time Graph : *v/t* graph :

(a) *v/t* graph for uniform motion :



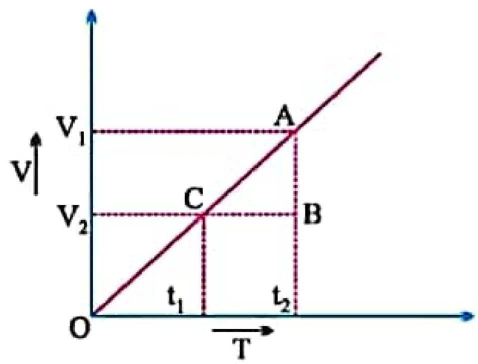
$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

But, $v_2 = v_1$

$$\therefore \quad a = \frac{0}{t_2 - t_1} \quad \text{Or} \quad a = 0$$

(b) *v/t* graph for non-uniform motion :

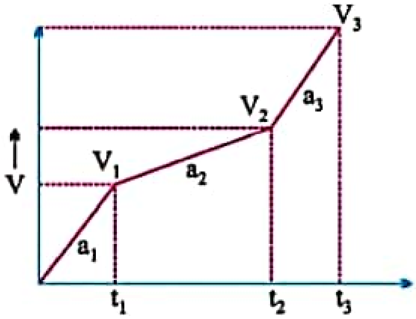
(A) *v/t* graph for accelerated (uniform) motion :



$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

In uniformly accelerated motion, there will be equal increase in velocity in equal interval of time throughout the motion of body.

(B) v/t graph for accelerated (non-uniform) motion :



Here if, $t_2 - t_1 = t_2 - t_3$

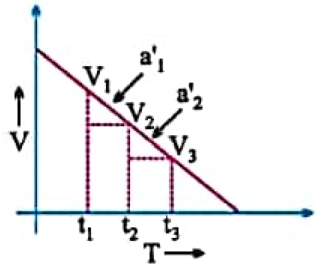
Then, $v_2 - v_1 \neq v_3 - v_2$

$$\frac{v_2 - v_1}{t_2 - t_1} \neq \frac{v_3 - v_2}{t_3 - t_2}$$

Or

Or $a_2 \neq a_1$

(C) v/t graph for decelerated (uniform) motion :



Here, $v_2 - v_1 = v_3 - v_2$

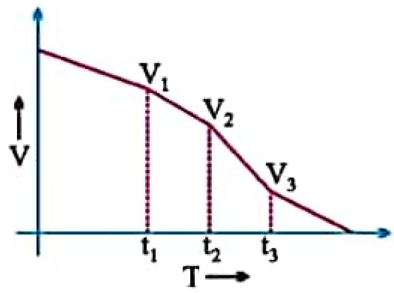
If $t_2 - t_1 = t_3 - t_2$

$$\frac{v_2 - v_1}{t_2 - t_1} = \frac{v_3 - v_2}{t_3 - t_2}$$

Then,

Or $a'_1 = a'_2$

(D) v/t graph for decelerated (non-uniform) motion :



Here, $v_2 - v_1 \neq v_3 - v_2$

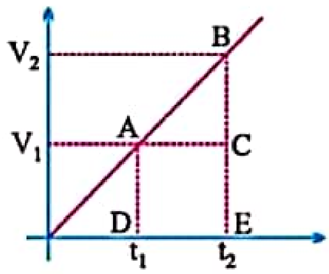
If $t_2 - t_1 = t_3 - t_2$

$$\frac{v_2 - v_1}{t_2 - t_1} \neq \frac{v_3 - v_2}{t_3 - t_2}$$

Then,

Or $a'_1 \neq a'_2$

Note : The area enclosed between any two time intervals is '$t_2 - t_1$' in v/t graph will represent the total displacement by that body.

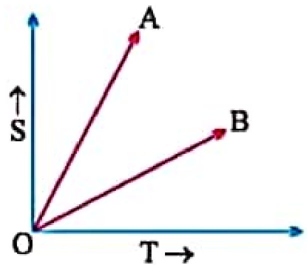


Total distance travelled by body between t_2 and t_1, time intervals

$$= \text{Area of } \Delta ABC + \text{Area of rectangle ACDB}$$

$$= \tfrac{1}{2} \times (v_2 - v_1) \times (t_2 - t_1) + v_1 \times (t_2 - t_1)$$

Example : *From the information given in s/t graph, which of the following body 'A' or 'B' will be more faster ?*



Solution : $V_A > V_B$

Equation of Motion (For Uniformly Accelerated Motion)

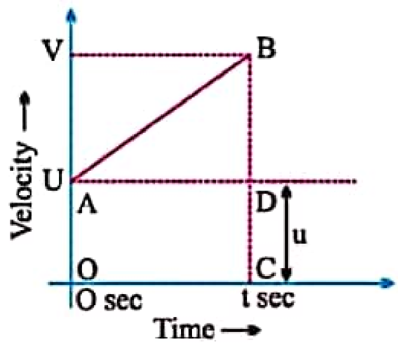
(i) First Equation

$$v = u + at$$

Or Final velocity = Initial velocity + Acceleration × Time

Graphical Derivation :

Suppose a body has initial velocity 'u' (*i.e.*, velocity at time $t = 0$ sec.) at point 'A' and this velocity changes to 'v' at point 'B' in 't' secs. *i.e.*, final velocity will be 'v'.



For such a body there will be an acceleration.

$$a = \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$a = \frac{OB - OA}{OC - 0} = \frac{v - u}{t - 0}$$

$$a = \frac{v - u}{t}$$

Or

Or $\quad v = u + at$

(ii) Second Equation

$$s = ut + \tfrac{1}{2}at^2$$

Distance travelled by object = Area of OABC (trapezium)

= Area of OADC (rectangle) + Area of ΔABD

= OA × AD + ½ × AD × BD

$= u \times t + \tfrac{1}{2} \times t \times (v - u)$

$= ut + \tfrac{1}{2} \times t \times at$

$\left(\because \frac{v-u}{t} = a\right)$

$$s = ut + \tfrac{1}{2}at^2$$

(iii) Third Equation

$$v^2 = u^2 + 2as$$

s = Area of trapezium OABC

$$s = \frac{(OA + BC) \times OC}{2}$$

$$s = \frac{(u+v) \times t}{2}$$

Or

$$s = \left(\frac{u+v}{2}\right) \times \left(\frac{v-u}{a}\right)$$

$\left(\because \frac{v-u}{t} = a\right)$

$$s = \frac{v^2 - u^2}{2a}$$

$\therefore$

Or $\quad v^2 = u^2 + 2as$

Example 1. *A car starting from rest moves with uniform acceleration of 0.1 ms^{-2} for 4 mins. Find the speed and distance travelled.*

Solution : $u = 0 \text{ ms}^{-1}$ $\quad \because$ car is at rest.

$a = 0.1 \text{ ms}^{-2}$

$t = 4 \times 60 = 240$ sec.

$v = ?$

From, $\quad v = u + at$

$v = 0 + 0.1 \times 240$

Or $\quad v = 24 \text{ ms}^{-1}$ **Ans.**

Example 2. *The brakes applied to a car produces deceleration of 6 ms^{-2} in opposite direction to the motion. If car requires 2 sec. to stop after application of brakes, calculate distance travelled by the car during this time.*

Solution : Deceleration, $a = -6 \text{ ms}^{-2}$

Time, $t = 2$ sec.

Distance, $s = ?$

Final velocity, $v = 0 \text{ ms}^{-1}$ $\quad \because$ car comes to rest.

Now, $\quad v = u + at$

Or $\quad u = v - at$

Or $\quad u = 0 - (-6) \times 2 = 12 \text{ ms}^{-1}$

And, $\quad s = ut + \frac{1}{2}at^2$

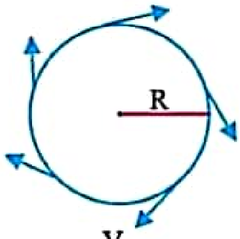
$= 12 \times 2 + \frac{1}{2} \times (-6) \times (2)^2$

$= 24 - 12 = 12$ m **Ans.**

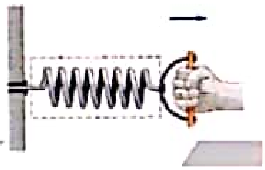
Uniform Circular Motion

If a body is moving in a circular path with uniform speed, then it is said to be executing uniform circular motion.

In such a motion the speed may be same throughout the motion but its velocity (which is tangential) is different at eact and every point of its motion. Thus, uniform circular motion is an accelerated motion.



Direction of velocity (Tangential)



Chapter - 6

Force And Laws Of Motion

CHAPTER AT A GLANCE

Force And Laws Of Motion

- **Force**
  Force (f) = Mass (m) × Acceleration (a)
  Unit = Newton
  - Balanced force
  - Unbalanced force
- **Newton's Law of Motion**
  - Newton's first law of motion
    - Inertia
    - Mass
  - Newton's second law of motion
    - force = m × a
      Momentum = mv
      Unit of momentum = kgm/s
  - Newton's third law of motion
    - Law of Conservation of momentum
    - Action – Reaction

Forces and Laws of Motion :

Force : It is the force that enables us to do any work. To do anything, either we pull or push the object. Therefore, pull or push is called force.

Example, to open a door, either we push or pull it. A drawer is pulled to open and

pushed to close.

Effect of Force

(i) Force can make a stationary body in object. For example, a football can be set to move by kicking it, *i.e.*, by applying a force.

(ii) Force can stop a moving body. For example, by applying brakes, a running cycle or a running vehicle can be stopped.

(iii) Force can change the direction of a moving object. For example, by applying force, *i.e.*, by moving handle, the direction of a running bicycle can be changed. Similarly by moving steering, the direction of a running vehicle is changed.

(iv) Force can change the speed of a moving body. By accelerating, the speed of a running vehicle can be increased or by applying brakes the speed of a running vehicle can be decreased.

(v) Force can change the shape and size of an object. For example, by hammering, a block of metal can be turned into a thin sheet. By hammering, a stone can be broken into pieces.

Forces are mainly of two types :

(A) Balanced forces

(B) Unbalanced forces

(A) Balanced Forces

- If the resultant of applied forces is equal to zero, it is called balanced forces.

  Example, in the tug of war if both the team apply similar magnitude of forces in opposite directions, rope does not move in either side. This happens because of balanced forces in which resultant of applied forces become zero.

- Balanced forces do not cause any change of state of an object. Balanced forces are equal in magnitude and opposite in direction.

- Balanced forces can change the shape and size of an object. For example, when forces are applied from both sides over a balloon, the size and shape of balloon is changed.

(B) Unbalanced Forces

- If the resultant of applied forces are greater than zero, the forces are called unbalanced forces. An object in rest can be moved because of applying balanced forces.
- Unbalanced forces can do the following :
  * Move a stationary object
  * Increase the speed of a moving object
  * Decrease the speed of a moving object
  * Stop a moving object
  * Change the shape and size of an object

Laws of Motion :

Galileo Galilei : Galileo first of all said that object move with a constant speed when no foces act on them. This means if an object is moving on a frictionless path and no other force is acting upon it, the object would be moving forever. That is, there is no unbalanced force working on the object.

- But practically it is not possible for any object. Because to attain the condition of zero, unbalanced force is impossible. Force of friction, force of air and many other forces are always acting upon an object.

Newton's Laws of Motion :

Newton studied the ideas of Galileo and gave the three laws of motion. These laws are known as Newton's laws of motion.

Newton's First Law of Motion (Law of Inertia) :

Any object remains in the state of rest or in uniform motion along a straight line, until it is compelled to change the state by applying external force.

Explanation : If any object is in the state of rest, then it will remain in rest until a external force is applied to change its state. Similarly, an object will remain in motion until any external force is applied over it to change its state. This means all objects resist to in changing their state. The state of any object can be changed by applying external forces only.

Newton's First Law of Motion in Everyday Life :

(a) A person standing in a bus falls backward when bus starts moving suddenly. This happens because the person and bus both are in rest while bus is not moving, but as the bus starts moving, the legs of the person start moving along with bus but rest portion of his body has the tendency to remain in rest. Because of this, the person falls backward; if he is not alert.

(b) A person standing in a moving bus falls forward if driver applies brakes suddenly. This happens because when bus is moving, the person standing in it is also in motion along with bus. But when driver applies brakes the speed of bus decreases suddenly or bus comes in the state of rest suddenly, in this condition the legs of the person which are in contact with the bus come in rest while the rest part of his body have the tendency to remain in motion. Because of this person falls forward if he is not alert.

(c) Before hanging the wet clothes over laundry line, usually many jerks are given to the clothes to get them dried quickly. Because of jerks, droplets of water from the pores of the cloth falls on the ground and reduced amount of water in clothes dries them quickly. This happens because when suddenly clothes are made in motion by giving jerks, the water droplets in it have the tendency to remain in rest and they are separated from clothes and fall on the ground.

(d) When the pile of coin on the carom-board is hit by a striker, coin only at the bottom moves away leaving rest of the pile of coin at same place. This happens because when the pile is struck with a striker, the coin at the bottom comes in motion while rest of the coin in the pile has the tendency to remain in the rest and they vertically falls the carom-board and remain at same place.

Mass and Inertia

- The property of an object because of which it resists to get disturb its state is called inertia. Inertia of an object is measured by its mass. Inertia is directly proportional to the mass. This means inertia increases with increase in mass and decreases with decrease in mass. A heavy object will have more inertia than the lighter one.
- In other words, the natural tendency of an object that resists the change in state of motion or rest of the object is called inertia.

- Since a heavy object has more inertia, thus it is difficult to push or pull a heavy box over the ground than the lighter one.

Momentum

- Momentum is the power of motion of an object.
- The product of velocity and mass is called the momentum. Momentum is denoted by 'p'.

  Therefore, Momentum of the object = Mass × Velocity

  Or, $p = m \times v$

Where, p = momentum, m = mass of the object and v = velocity of the object.

Consider the following explanations to understand the momentum :

- A person get injured in the case of hitting by a moving object, such as stone, pebbles or anything because of momentum of the object.
- Even a small bullet is able to kill a person when it is fired from a gun because of its momentum due to great velocity.
- A person get injured severely when hit by a moving vehicle because of momentum of vehicle due to mass and velocity.

Momentum and Mass and Velocity

- Since momentum is the product of mass and velocity ($p = m \times v$) of an object. This means momentum is directly proportional to mass and velocity. Momentum increases with increase of either mass or velocity of an object.
- This means if a lighter and a heavier object is moving with same velocity, then heavier object will have more momentum than the lighter one.
- If a small object is moving with great velocity, it has tremendous momentum. And because of momentum, it can harm an object more severely. For example, a small bullet having a little mass even kills a person when it is fired from a gun.
- Usually, road accidents prove more fatal because of high speed than in slower speed. This happens because vehicles running with high speed have greater momentum compared to a vehicle running with slower speed.

Momentum of an object which is in the state of rest :

Let an object with mass 'm' is in the rest.

Since, object is in rest, therefore, its velocity, $v = 0$

Now, we know that

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

Or $$p = m \times 0 = 0$$

Thus, the momentum of an object in the rest *i.e.*, non-moving, is equal to zero.

Unit of momentum :

SI unit of mass = kg

SI unit of velocity = meter per second *i.e.*, m/s

We know that $$\text{Momentum } (p) = m \times v$$

Therefore, $$p = \text{kg} \times \text{m/s}$$

Or $$p = \text{kg m/s}$$

Therefore, SI unit of momentum = kg m/s

Numerical Problems Based on Momentum

Type I. Calculation of Momentum

Example 1. *What will be the momentum of a stone having mass of 10 kg when it is thrown with a velocity of 2 m/s ?*

Solution : Mass (m) = 10 kg

Velocity (v) = 2 m/s

Momentum (p) = ?

We know that, $$\text{Momentum } (p) = \text{Mass } (m) \times \text{Velocity } (v)$$

Therefore, $$p = 10 \text{ kg} \times 2 \text{ m/s} = 20 \text{ kg m/s}$$

Thus, the momentum of the stone = 20 kg m/s. **Ans.**

Example 2. *Calculate the momentum of a bullet of 25 g when it is fired from a gun with a velocity of 100 m/s.*

Solution : Given, Velocity of the bullet (v) = 100 m/s

Mass of the bullet (m) = 25 g = 25/1000 kg = 0.025 kg

Momentum (p) = ?

Since, $p = m \times v$

So, $p = 0.025 \times 100 = 2.5$ kg m/s

Thus, momentum of the bullet = 2.5 kg m/s. **Ans.**

Example 3. *Calculate the momentum of a bullet having mass of 25 g is thrown using hand with a velocity of 0.1 m/s.*

Solution : Given, Velocity of the bullet (v) = 0.1 m/s

Mass of the bullet (m) = 25 g = 25/1000 kg = 0.025 kg

Momentum (p) = ?

We know that, Momentum (p) = Mass (m) × Velocity (v)

Therefore, $p = 0.025$ kg × 0.1 m/s

Or $p = 0.0025$ kg m/s

Thus, the momentum of the bullet = 0.0025 kg m/s. **Ans.**

Example 4. *The mass of a goods lorry is 4000 kg and the mass of goods loaded on it is 20000 kg. If the lorry is moving with a velocity of 2 m/s, what will be its momentum ?*

Solution : Given, Velocity (v) = 2 m/s

Mass of lorry = 4000 kg, Mass of goods on the lorry = 20000 kg

Therefore, Total mass (m) on the lorry = 4000 kg + 20000 kg = 24000 kg

Momentum (p) = ?

We know that, Momentum (p) = Mass (m) × Velocity (v)

Therefore, $p = 24000$ kg × 2 m/s

Or $p = 48000$ kg m/s

Thus, the momentum of the lorry = 48000 kg m/s. **Ans.**

Example 5. *A car having mass of 1000 kg is moving with a velocity of 0.5 m/s. What will be its momentum ?*

Solution : Given, Velocity of the car (v) = 0.5 m/s

Mass of the car (m) $= 1000$ kg

Momentum (p) = ?

We know that, Momentum (p) = Mass (m) × Velocity (v)

Therefore, $p = 1000 \text{ kg} \times 0.5 \text{ m/s} = 500 \text{ kg m/s}$

Thus, momentum of the car = 500 kg m/s. **Ans.**

Statement of Second Law

Rate of change of momentum of an object is proportional to applied unbalanced force in the direction of force.

Mathematical expression

Suppose, Mass of an object = m kg

Initial velocity of an object = u m/s

Final velocity of an object = v m/s

So, Initial momentum, $p_1 = mu$, Final momentum, $p_2 = mv$

$\therefore$ Change in momentum = Final momentum – Initial momentum

$= mv - mu$

$= m(v - u)$

$\therefore$ Rate of change of momentum $= \dfrac{\text{Change in momentum}}{\text{Time taken}}$

$$= \frac{m(v-u)}{t}$$

- According to IInd law, this rate of change is momentum is directly proportional to force.

$$\therefore \quad F \propto \frac{m(v-u)}{t}$$

We know that, $\dfrac{v-u}{t} = a$ (From Ist equation of motion)

So, $F = kma$

Where k is a constant. Its value = 1.

$\therefore$ $F = 1 \times m \times a = ma$

SI unit $= \text{kg m/s}^2$ or Newton

Q. Define 1 Newton.

Ans. When an acceleration of 1 m/s^2 is seen in a body of mass 1 kg, then the force applied on the body is said to be 1 Newton.

Proof of Newton's First Law of Motion from Second Law

First law states that if external force F = 0, then a moving body keeps moving with the same velocity, or a body at rest continues to be at rest.

So, $F = 0$

We know $F = \dfrac{m(v-u)}{t}$

(a) A body is moving with initial velocity u, then

$$0 = \frac{m(v-u)}{t} \quad \Rightarrow \quad v - u = 0$$

So, $v = u$

Thus, final velocity is also same.

(b) A body is at rest *i.e.*, $u = 0$.

Therefore, from above $u = v = 0$

So, the body will continue to be at rest.

Third Law of Motion

To every action there is an equal an opposite reaction.

Applications :

(i) Walking is enabled by IIIrd law.

(ii) A boat moves back when we deboard it.

(iii) A gun recoils.

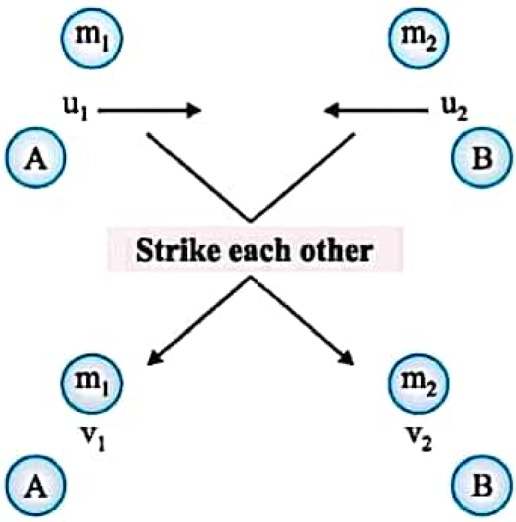
(iv) Rowing of a boat.

Law of Conservation of Momentum

When two (or more) bodies act upon one another, their total momentum remains constant (or conserved) provided no external forces are acting.

Initial momentum = Final momentum

Suppose, two objects A and B each of mass m_1 and mass m_2 are moving initially with velocities u_1 and u_2, strike each other after time t and start moving with velocities v_1 and v_2 respectively.



Now,

Initial momentum of object A = m_1u_1

Initial momentum of object B = m_2u_2

Final momentum of object A = m_1v_1

Final momentum of object B = m_2v_2

So, Rate of change of momentum in A, $F_1 = \frac{m_1v_1 - m_1u_1}{t}$

$$= \frac{m_1(v_1 - u_1)}{t} \quad \text{...(i)}$$

And Rate of change of momentum in B, $F_2 = \dfrac{m_2 v_2 - m_2 u_2}{t}$

$$= \frac{m_2 (v_2 - u_2)}{t} \qquad \text{...(ii)}$$

We know from IIIrd law of motion,

$$F_1 = -F_2$$

So, $\dfrac{m_1 (v_1 - u_1)}{t} = -\dfrac{m_2 (v_2 - u_2)}{t}$ [From equations (i) & (ii)]

Or $m_1 v_1 - m_2 v_2 = - m_2 v_2 + m_2 u_2$

So $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

Thus, Initial momentum = Final momentum

Example 1. *A bullet of mass 20 g is fired horizontally with a velocity of 150 m/s from a pistol of mass 2 kg. Find the recoil velocity of the pistol.*

Solution : Given, Mass (m_1) of bullet = 20 g = 0.02 kg

Mass (m_2) of pistol = 2 kg

Initially bullet is inside the gun and it is not moving.

So, Mass $= m_1 + m_2 = (0.02 + 2)$ kg = 2.02 kg

And $u_1 = 0$

So, Initial momentum $= 2.02 \times 0 = 0$ ...(i)

Finally let the velocity of pistol be v_2 and v_1 for bullet = 150

So, Final momentum $= m_1 v_1 + m_2 v_2$

$$= 0.02 \times 150 + 2v_2 \qquad \text{...(ii)}$$

We know that Initial momentum = Final momentum

So, $0 = \dfrac{0.02 \times 150}{100} + 2v_2$ [From equations (i)

and (ii)]

$\Rightarrow \qquad 3 + 2v_2 = 0$

Or $\qquad 2v_2 = -3$

Or $\qquad v_2 = -1.5$ m/s **Ans.**

(–)ve sign indicates that gun recoils in direction opposite to that of the bullet.

Example 2. *Two hockey players viz A of mass 50 kg is moving with a velocity of 4 m/s and another one B belonging to opposite team with mass 60 kg is moving with 3 m/s, get entangled while chasing and fall down. Find the velocity with which they fall down and in which direction ?*

Solution : Given, $\qquad m_A = 50$ kg, $u_A = 4$ m/s

$m_B = 60$ kg, $u_B = 3$ m/s

Initial momentum$_A$ $= m_A u_A$

$= 50 \times 4 = 200$ kg m/s

Initial momentum$_B$ $= m_B u_B$

$= 60 \times 3 = 180$ kg m/s

So, Total initial momentum $= 200 + 180 = 380$ kg m/s ...(i)

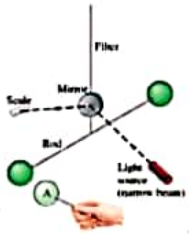
Final momentum $= (m_A + m_B)v = (50 + 60)v$

$= 110v$ ...(ii)

According to the law of conservation of momentum,

$$380 = 110v$$

Or $\qquad v = \dfrac{380}{110} = 3.454$ m/s **Ans.**



Chapter - 7

Gravitation

CHAPTER AT A GLANCE

Gravitation

reaction

Newton's Universal law of gravitation

Force (f) = $\frac{GM_1M_2}{R^2}$

G = Gravitational Constant

M_1 = Mass of object 1

M_2 = Mass of object 2

R = distance between object

W = m × g
Weight = Mass × Gravity

Buoyant force 'f'

Trust → Pressure

P = F/A

P = Pressure

F = Force

A = Area

Acceleration due to gravity (g) = 9.8 m/s^2

g = $\frac{GM}{R^2}$

R = Radius of Earth

M = Mass of Earth

G = Gravitational constant

Value of G = 6.67×10^{-11} Nm^2/kg^2

Gravitational Force of Earth

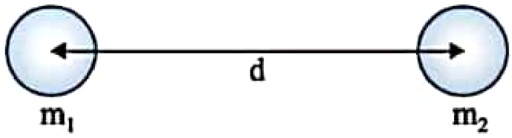
If we release a small stone without pushing it from a height, it accelerates towards earth. The stone is when accelerated towards earth, means some force is acting on it.

The force which pulls the objects towards the centre of the earth is known as gravitational force of the earth.

Here, stone also attracts earth. It means every object in universe attracts every other object.

Newton's Universal Law of Gravitation

Sir Isaac Newton in 1687 proposed a law about the force of attraction between the two objects in the universe which is known as Newton's law of gravitation.



According to this law :

Every mass in this universe attracts every other mass with a force which is directly proportional to the product of two masses and inversely proportional to the square of the distance between them.

Let masses (m_1) and (m_2) of two objects are distance (d) apart, then force of attraction (F) between them

$$F \propto m_1 \times m_2$$

$$F \propto \frac{1}{d^2}$$

$$F \propto \frac{m_1 \times m_2}{d^2}$$

$$F = \frac{Gm_1 \times m_2}{d^2}$$

where G is a constant and is known as Gravitational constant.

> Value of G = 6.67×10^{-11} Nm^2/kg^2
> G is called universal gravitational constant.

If unit of F is in Newton, m is in kg, d is in metre, then unit of G can be calculated as :

$$G = \frac{F \times d^2}{m_1 \times m_2} \text{ so unit be } \frac{Nm^2}{kg^2} \text{ or } Nm^2/kg^2$$

Relation between Newton's third law of motion and Newton's law of gravitation

According to Newton's third law of motion, "Every object exerts equal and opposite force on other object but in opposite direction."

According to Newton's law of gravitation, "Every mass in the universe attracts the every other mass."

In case of freely falling stone and earth, stone is attracted towards earth means earth attracts the stone but according to Newton's third law of motion, the stone should also attract the earth and really it is true that stone also attracts the earth with the same force $F = m \times a$ but due to very less mass of the stone, the acceleration (a) in its velocity is 9.8 m/s^2 and acceleration (a) of earth towards stone is 1.65×10^{-24} m/s^2 which is negligible and we cannot feel it.

Importance of universal law of gravitation

(i) The force that binds us to the earth.

(ii) The motion of moon around the earth.

(iii) The motion of earth around the sun.

(iv) The tides due to moon and the sun.

Free fall of an object and acceleration during free fall

When an object is thrown upward, it reaches certain height, then it starts falling down towards earth. It is because the earth's gravitational force exerts on it.

This fall under the influence of earth is called 'free fall of an object'.

During this free fall direction do not change but velocity continuously changes which is called acceleration due to gravity.

It is denoted by 'g'.

Its unit is same as acceleration m/s^2.

Gravitational Acceleration and its value at the surface of earth

The uniform acceleration produced in a freely falling object due to the gravitational force of earth, is called acceleration due to gravity. It is represented by 'g' and it always acts towards the centre of the earth.

Value of 'g' on the surface of earth

The force acting on an object is

$$F = \frac{GM_e m}{R^2} \qquad ...(i)$$

Where M_e = Mass of earth

m = Mass of an object

R = Radius of earth

and if acceleration due to gravity is 'g' due to force F then,

$$F = m \times g \quad \text{...(ii)}$$

Equating (i) and (ii), we get $m \times g = \dfrac{GM_e m}{R^2}$

Or $g = \dfrac{GM_e}{R^2}$

If $G = 6.673 \times 10^{-11}$ Nm²/kg², $M_e = 6 \times 10^{24}$ kg, $R^2 = (6.37 \times 10^6)^2$

Then, $g = \dfrac{6.6734 \times 10^{-11} \times 6 \times 10^{24}}{(6.37 \times 10^6)^2}$

$$g = 9.8 \text{ m/s}^2$$

Relationship and difference between 'G' and 'g'

G = Gravitational constant

g = Acceleration due to gravity

$$g = \frac{GM}{R^2}$$

Difference between G (Gravitational constant) and *g* (Acceleration due to gravity)

Gravitation Constant (G)	Gravitational acceleration (g)
1. Its value is 6.6734×10^{-11} Nm²/kg².	1. Its value is 9.8 m/s².
2. Its value remains constant always and everywhere.	2. Its value varies at various places.
3. Its unit is Nm²/kg².	3. Its unit is m/s².
4. It is a scalar quantity.	4. It is a vector quantity.

Example. *If two stones of 150 gm and 500 gm are dropped from a height, which stone will reach the surface of earth first and why ? Explain your answer.*

Ans. It was Galileo, who first time demonstrated and depicted that the acceleration of an object falling freely towards earth does not depend on the mass of the object.

It can be verified by universal law of gravitation. Let an object of mass m, is allowed to fall from a distance of R, from the centre of the earth.

Then, the gravitational force, $F = \frac{GM_e m}{R^2}$ (M_e = Mass of the earth)

The force acting on the stone is $F = m \times a$

So, $m \times a = \frac{GM_e m}{R^2}$

Or $a = \frac{GM_e}{R^2}$

So, acceleration in an object falling freely towards earth depends on the mass of earth and height of the object from the centre of the earth. So stones of mass 150 gm and 500 gm will reach the earth surface together.

Equation of motion when an object is falling freely towards earth or thrown vertically upwards :

Case 1. When an object is falling towards earth with initial velocity (u), then

Velocity (v) after t seconds, $v = u + ght$

Height covered in t seconds, $h = ut + \frac{1}{2}gt^2$

Relation between v and u when t is not mentioned :

$$v^2 = u^2 + 2gh$$

Case 2. When object is falling from rest position means initial velocity $u = 0$ (zero), then

Velocity (v) after t seconds, $v = gt$

Height covered in t seconds, $h = \frac{1}{2}gt^2$

Relation between v and u when t is not mentioned :

$$v^2 = 2gh$$

Case 3. When an object is thrown vertically upwards with initial velocity u, the gravitational acceleration will be negative ($-g$), then

Velocity (v) after t seconds, $v = u - gt$

Height covered in t seconds, $h = ut - \frac{1}{2}gt^2$

Relation between v and u when t is not mentioned :

$$v^2 = u^2 - 2gh$$

Mass

The mass of a body is the quantity of matter contained in it. Mass is a scalar quantity which has only magnitude but no direction.

SI unit of mass is kilogram which is written in short form as kg.

- Mass of a body is constant and does not change from place to place.
- Mass of a body is usually denoted by the small 'm'.
- Mass of a body cannot be zero.

Weight

The force with which an object is attracted towards the centre of the earth, is called the weight of the object.

$$\text{Force} = m \times a$$

In case of earth, $a = g$

So, $F = m \times g$

But the force of attraction of earth on an object is called its weight (W). So,

$$W = m \times g$$

So, weight is the force and its SI unit is Newton (N). It depends on 'g' and is a vector quantity.

Relation between 1 kg wt and express it into Newton :

We know that $W = m \times g$

If mass (m) = 1 kg, $g = 9.8\ m/s^2$, then

$$W = 1\ kg \times 9.8\ m/s^2$$

Or $1\ kg\ wt = 9.8N$

So, the gravitational force of earth that acts on an object of mass 1 kg is called as 1 kg wt.

Distinguish between Mass and Weight

Mass	Weight
1. We can measure mass of an object by its inertia.	1. Weight = mass × acceleration or $m \times g$.
2. The total quantity of matter contained in an object is called mass of an object.	2. The gravitational force by which earth attracts an object is called weight of the object.
3. Mass of the object remains constant at all the places.	3. Weight of the object is different at different places.
4. Measurement of mass is done by using a pan or beam balance.	4. Measurement of weight is done by using a spring balance.

5. Mass does not change even value of g is zero at any place.	5. Weight of the object becomes zero if g is zero.

Factors affecting value of g

Earth is not a perfect sphere. The radius of earth increases when we go from pole to equator. Therefore, in most of the calculation, we can take g as constant at the surface of earth or closer to it. But, as we move away from earth, we can use equation $g = \frac{GM}{d^2}$ for solving problems.

Example. *Calculate the value of 'g' at a height of 12800 km from the centre of the earth (radius of earth is 6400 km). Draw its interpretation.*

Solution : We know that $g_1 = \frac{GM_e}{(2R_e)^2}$, $R_e = 6400$ km

Weight of the object from the centre of earth = 12800 km = $2R_e$

$$\therefore \quad g_2 = \frac{GM_e}{(2R_e)^2}$$

Or $$\frac{g_1}{g_2} = \frac{G \cdot M_e}{(R_e)^2} \times \frac{(2R_e)^2}{G \cdot M_e}$$

$$\frac{g_1}{g_2} = \frac{4}{1} \quad \text{Or} \quad 4g_2 = g_1$$

So, the value of gravitational acceleration 'g' at a distance of 12800 km from the centre of the earth is ¼.

The value of gravitational acceleration 'g' decreases with increasing height.

The weight of an object on moon is one-sixth of the weight on earth.

Let mass of an object be m, its weight on earth means the force by which earth attracts it towards the centre.

Now, $$F_e = \frac{GM_e m}{R_e^2} \quad \text{...(i)}$$

where G = Gravitational constant, M_e = Mass of the earth, m = Mass of object, R_e = Radius of the earth

Weight of an object on moon,

$$F_m = \frac{GM_m m}{R_m^2} \quad \text{...(ii)}$$

where M_m = Mass of the moon, R_m = Radius of the moon

Dividing equation (i) by equation (ii), we get

$$\frac{F_e}{F_m} = \frac{GM_e \cdot m}{R_e^2} \times \frac{R_m^2}{GM_m \cdot m}$$

$$\frac{F_e}{F_m} = \frac{M_e}{M_m} \times \left(\frac{R_m}{R_e}\right)^2$$

We know that mass of earth is 100 times the mass of the moon.

So, $M_e = 100M_m$

And radius of earth is 4 times the radius of moon.

So, $R_e = 4R_m$

Then,

$$\frac{F_e}{F_m} = \frac{100M_m}{M_m} \times \left(\frac{R_m}{4R_m}\right)^2$$

$$\frac{F_e}{F_m} = \frac{100}{1} \times \frac{1}{16}$$

$$\frac{F_e}{F_m} = 6 \text{ times (approx.)}$$

Hence, $F_e = 6F_m$

Thrust and Pressure

Thrust : The force acting on an object perpendicular to the surface is called thrust.

Pressure : The effect of thrust per unit area is called pressure.

$$\text{Pressure (P)} = \frac{\text{Force (F)}}{\text{Area (A)}}$$

SI unit is N/m^2 or Nm^{-2}.

SI unit of pressure is Pascal denoted by 'Pa'.

Factors on which pressure depends

Pressure depends on two factors :

(i) Force applied

(ii) Area of surface over which force acts

Examples :

- The base of high buildings is made wider so that weight of walls act over a large surface area and pressure is less.
- School bags are having broad strap so that the weight of school bags fall over a larger area of the shoulder and produce less pressure and becomes less painful.
- The blades of knives are made sharp so very small surface area and on applying force, it produces large pressure and cuts the object easily.
- All liquids and gases are fluids and they exert pressure in all directions.

Buoyancy

The upward force experienced by an object when it is immersed into a fluid is called force of buoyancy. It acts in upward direction and it depends on the density of the fluid.

- Force of gravitational attraction of the earth on the surface of the object $\leq$ buoyant force exerted by fluid on the surface of the object.

Result : The object floats.

- Force of gravitational attraction of the earth on the surface of the object > buoyant force exerted by fluid on the surface of the object.

Result : The object sinks.

That is why, allpin sinks and boat/ship floats on the surface of water. (Archimedes' principle)

Density

The mass per unit volume is called density of an object. If M is the mass and V is the volume, then density (d) is

$$\text{Density } (d) = \frac{\text{Mass (M)}}{\text{Volume (V)}}$$

SI unit = kg/m^3

Archimedes' Principle

It states, when a body is immersed fully or partially in a fluid, it experiences a upward force that is equal to the weight of the fluid displaced by it.

Applications of Archimedes' Principle :

(i) It is used in determining relative density of substances.

(ii) It is used in designing ships and submarines.

(iii) Hydrometers and lactometers are made on this principle.

It is because of this ship made of iron and steel floats in water whereas a small piece of iron sinks in it.

Relative density

The ratio of the density of a substance to that of the density of water is called relative density.

$$\text{Relative density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

It has no unit.

Solved Numericals

Example 1. *Relative density of gold is 19.3. The density of water is 10^3 kg/m^3. What is the density of gold in kg/m^3 ?*

Solution : Given, Relative density of gold = 19.3

Density of water = 10^3 kg/m^3

So, Density of gold = Relative density of gold × Density of water

$= 19.3 \times 10^3$

Hence, density of gold $= 19.3 \times 10^3$ kg/m^3. **Ans.**

Example 2. *Mass of 0.025 m^3 of aluminium is 67 kg. Calculate the density of aluminium.*

Solution : Given, Mass of aluminium = 67 kg

Volume of aluminium = 0.025 m^3

So, Density $= \frac{M}{V} = \frac{67}{0.025}$

= 2680 kg/m^3 **Ans.**

Example 3. *The mass of brick is 2.5 kg and its dimensions are 20 cm × 10 cm × 5 cm. Find the pressure exerted on the ground when it is placed on the ground with different faces.*

Solution : Given, Mass of the brick = 2.5 kg

Dimensions of the brick = 20 cm × 10 cm × 5 cm

So, Weight of the brick (Thrust/Force)

$= F = mg = 2.5 \times 9.8 = 24.5$ N

(i) When the surface area 10 cm × 5 cm is in contact with the ground, then

$$\text{Area} = 10 \times 5 = 50 \text{ cm}^2$$

$$= \frac{50}{10000} = 0.005 \text{ m}^2$$

So, $$P = \frac{F}{A} = \frac{24.5}{0.0050}$$

$$= 4900 \text{ N/m}^2$$ **Ans.**

(ii) When the surface area 20 cm × 5 cm is in contact with the ground, then

$$\text{Area} = 20 \times 5 = 100 \text{ cm}^2$$

$$= \frac{100}{10000} = 0.01 \text{ m}^2$$

So, $$P = \frac{F}{A} = \frac{24.5}{0.01}$$

$$= 2450 \text{ N/m}^2$$ **Ans.**

(iii) When the surface area 20 cm × 10 cm is in contact with the ground, then

$$\text{Area} = 20 \times 10 = 200 \text{ cm}^2$$

$$= \frac{200}{10000} = 0.02 \text{ m}^2$$

So, $$P = \frac{F}{A} = \frac{24.5}{0.02}$$

$$= 1225 \text{ N/m}^2$$ **Ans.**

Example 4. *A force of 20N acts upon a body whose weight is 9.8N. What is the mass of the body and how much is its acceleration ?*

Solution : Given, Force = 20N, Weight W = 9.8N

We know, $W = mg$

So, $9.8 = m \times 9.8$

Or $m = 1$ kg **Ans.**

And, $F = ma$

So, $20 = 1 \times a$

Or $a = 20 \text{ m/s}^2$ **Ans.**

Example 5. *A man weighs 1200N on the earth. What is his mass (take g = 10 m/s²) ? If he was taken to the moon, his weight would be 200N. What is his mass on*

moon ? What is his acceleration due to gravity on moon ?

Solution : Given, Weight of man on earth W_1 = 1200 N

Weight of man on moon W_2 = 200 N

Gravitational acceleration of earth = 10 m/s^2

Now, $W = mg$

Or $m = W/g$

$= 120$ kg

So, mass on moon will be 120 kg as it is constant everywhere so mass of man on moon = 120 kg. **Ans.**

Now, $W_2 = mg_2$

Or $200 = 120 \times g$

Or $$g = \frac{200}{120} = \frac{10}{6} = \frac{5}{3}$$

$= 1.66$ m/s^2 **Ans.**

Example 6. *An object is thrown vertically upwards and reaches a height of 78.4 m. Calculate the velocity at which the object was thrown ? (g = 9.8 m/s^2)*

Solution : Given, $h = 78.4$ m, $v = 0$, $g = 9.8$ m/s^2, $u = ?$

$v^2 = u^2 - 2gh$

Or $0 = u^2 - 2 \times 9.8 \times 78.4$

Or $$u^2 = \frac{2 \times 98 \times 784}{10 \times 10}$$

Or $$u = \sqrt{\frac{2 \times 2 \times 49 \times 784}{10 \times 10}}$$

$$u = \frac{2 \times 7}{10}\sqrt{784}$$

Or $u = 39.2$ m/s^2 **Ans.**

Example 7. *What is the mass of an object whose weight is 49 Newton ?*

Solution : Given, Weight of object W = 49N

$g = 9.8$ m/s^2

Now, $W = mg$

Or $$m = \frac{W}{g} = \frac{49}{9.8}$$

$= 5$ kg **Ans.**